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ABSTRACT

Analogies are considered an effective method for providing a bridge between unfamiliar concepts and knowledge that students already have. This paper reports a critical analysis of analogies found in chemistry textbooks used by Australian senior high school students and is presented in three sections. The first section of the paper presents the definition of analogy and discusses different types of analogies, their use in teaching, and potential constraints to their effective use. The second section reports a two-part study of 10 chemistry textbooks. A content analysis: indicated that 93 analogies were found in the 10 textbooks; compared the frequency of analogy use for particular targeted content areas; identified textbook authors' incorporation of instructional strategies that aim to directly assist the student to use analogies to aid understanding; and examined the type of analogies used most frequently in the textbooks. Secondly, interviews were conducted with the authors of 7 of the 10 textbooks to solicit views held by the authors concerning: analogy use; reasons for inclusion or exclusion of analogies; and changes the author would make to a later edition of a textbook. Conclusions reported in the third section indicated that: (1) authors assumed classroom teachers would effectively use the analogies, despite no evidence that teachers have pedagogical content knowledge in this area; (2) the frequency of analogy inclusion implies an unwillingness by authors to use analogies in textbook situations; and (3) the authors are unfamiliar with research guides regarding analogy presentation results. A list of 21 references and an appendix of the textbook titles are provided. (MDH)

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Analogies in Senior High School Chemistry Textbooks:

A Critical Analysis

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Introduction

A currently supported view of learning is that when learners construct their own knowledge, it is both transferable to and usable in later learning situations. Recent research has shown that a significant factor enabling the creation of conditions where this type of learning occurs is related to teachers' subject matter understanding (Shulman, 1986; Kennedy, 1990). Of special importance is the teachers' content-specific pedagogical knowledge (Shulman,1986). One aspect of this knowledge is the use of analogies which can effectively communicate concepts to students of particular backgrounds and prerequisite knowledge. Since students often lack the background to learn difficult and unfamiliar topics encountered in chemistry, one effective way to deal with this problem is for the teacher to provide a bridge between the unfamiliar concept and the knowledge which students have; this bridge can be provided by analogies. However, although analogies have been used in chemistry teaching in a variety of contexts (see for example, the work by Gabel and Sherwood,1980), little research has been conducted in regular classroom settings about how chemistry teachers use analogies or how written materials which involve analogies are used by teachers and students. Consequently, there is need for research to investigate for whom and under what conditions analogies are most beneficial in chemical education.

In addressing this problem, a comprehensive research investigation is underway in chemistry education at the Science and Mathematics Education Centre at Curtin University of Technology to identify, examine and interpret those analogies used by authors of textbooks and by classroom teachers and their students at the secondary level. This research involves an examination of chemistry textbooks and interviews with the authors as well as observing and interviewing teachers and their students who are engaged in learning through the use of analogies in regular classroom settings. Similar studies are planned and also underway in physics and biology education.

To assist in the explaining of abstract chemical concepts, teachers and textbook authors may help students achieve conceptual understanding by employing teaching tools such as analogies. An analogy can allow new material to be more easily assimilated with the students' prior knowledge enabling those who do not readily think in abstract terms to develop a better understanding of the concept. Over the last ten years, heightened interest concerning the use of analogies in science education has resulted in the clarification of the picture of the types of analogies that are available and their range of presentation styles.

However, the use of analogies does not always produce the intended effects since some students take the analogy too far and are unable to separate it from the content being learned. Other students only remember the analogy and not the content under study

whilst yet others focus upon extraneous aspects of the analogy to form spurious conclusions relating to the target content.

Recently, models have been developed which can be used as guide-lines for teachers and textbook authors concerning more effective analogy use and a classification system has been developed that enables researchers to systematically characterize textbook analogies. For example, both Glynn et al. (1989) and Zeitoun (1984) have presented model approaches to analogy teaching and the inclusion of analogies in textual materials. Whilst these reports are more recent than some of the textbooks under study, it is important to consider the possibility that the implications of these studies are not reaching textbook authors and curriculum designers. If this is the case, then we can expect that future editions of textbooks by these, and other, authors will continue to present analogies in what some researchers (e.g. Curtis & Reigeluth, 1984; Duit, 1991; Glynn et al., 1989; Thiele & Treagust, 1991; Webb, 1985) consider to be a less than efficient manner.

This study involves a critical analysis of analogies found in chemistry textbooks used by Australian senior high school students, followed by an interpretive analysis of the views expressed by most of the authors of those books about the use of analogies in chemistry textbooks and chemistry teaching.

Defining an Analogy

There is a need to clearly define what an analogy is so that it is not confused with illustrations, models, and examples. For the purpose of this study, the researchers have adopted Glynn et al's. (1989) working definition:

> An analogy is a correspondence in some respects between concepts, principles, or formulas otherwise dissimilar. More precisely, it is a mapping between similar features of those concepts, principles, and formulas. (p. 383)

The analogy requires the selection of a student world analog to assist in the explanation of the content specific target (or topic). The analog and target share attributes that allow for a relationship to be identified. Important in the presentation of a good analogy is some evidence of mapping. This process involves a systematic comparison of the corresponding analog and target attributes so that students are fully aware of which conclusions to draw concerning the target concept being addressed. It must be considered that both the analog and the target have many attributes that are not shared. Good mapping also gives some indication as to where this occurs so that unshared attributes are not ascribed to the target domain.

Different Types of Analogies

Reviews of analogy related literature (e.g. Duit, 1991) highlight a range of types of analogies which include verbal, pictorial, personal, bridging, and multiple analogies, some of which are discussed below. Further, Curtis and Reigeluth (1984), in an analysis of 52 analogies from four American chemistry textbooks, proposed several other criteria by which analogies may be further classified by their integral parts. These criteria include an analysis of the nature of the shared attributes (structural or functional), the degree of explanation concerning the analog, as well as the level of enrichment of the analogy (the extent to which the author mapped the shared attributes). It is also evident that the final

presentation by the classroom teacher will have a considerable influence upon the mode of operation of the analogy.

Verbal and Pictorial Analogies: Those analogies which include only written text or oral presentation are called verbal analogies. As this type of analogy is often subtly embedded in the body of the text, the reader is usually left to draw the necessary comparisons and conclusions about the target from the description of the analog if one is provided. Alternatively, a pictorial analogy, which includes some pictorial representation of the analog domain, allows the textbook author or teacher to pictorially highlight the desired attributes of the analog. This method helps provide a greater degree of visualization which reduces the likelihood that the student is not sufficiently familiar with the analog. Most pictorial analogies are accompanied by some verbal explanation and hence technically should be referred to as pictorial-verbal analogies.

Personal Analogies: This type of analogy is believed to assist students by relating abstract chemical concepts to student world phenomena such as people, money, food, and relationships. For example, the text may encourage the students to imagine that they are packaging sausages and rissoles into barbecue packs with each pack containing exactly two sausages and one rissole. This may be shown to be analogous to a stoichiometrically reacting system and the effect of a limiting reagent on the amount of product and excess reagent remaining in the system. Marshall (1984) suggests that this type of analogy causes better learning of concepts and that the approach is more enjoyable although she warns that personal analogies can cause students to give intuitive feelings to inanimate objects and concepts.

The Advantages of Analogies in Teaching

Analogies are believed to help in three major ways in that they: a) provide visualization of abstract concepts; b) help compare similarities of the students' real world with the new concepts; and c) have a motivational function.

Visualization Process: Researchers (Glynn et al., 1989; Shapiro, 1985) agree that the visualization process is very important in the learning of concepts and that the analogies prompt a visualization process to aid understanding. In an analysis of 216 analogies found in science textbooks for secondary students, Curtis and Reigeluth (1984) found that chemistry textbooks contained the highest percentage of pictorial analogies (29%) compared to the total science average of only 16%.

Real World Linkage: It has been proposed that analogies have been historically linked to both the explaining of science and to the processes of science. Well renowned theorists such as Maxwell, Rutherford, and Einstein are reported to have used analogical reasoning as a tool to aid problem solving, to explain hypotheses, and to communicate to audiences about early theories of atomic structure (Lewis & Slade, 1981; Shapiro, 1985). Needless to say, analogies are used more frequently when the target domain is difficult to understand or is foreign to the learner (Duit, 1991). The presentation of a concrete analog in this situation facilitates understanding of the abstract concept by pointing to the similarities between objects or events in the learners' world and the phenomenon under discussion.

Motivational Function: The motivational sense of analogy is due to a number of factors. As the teacher or textbook author is drawing from the students' real world experience, a sense of intrinsic interest is generated. In addition to this interest, students who

traditionally perform at lower academic levels may be more likely to achieve a greater level of conceptual understanding. This should result in a motivational gain for the students. However, it should be noted that little has been determined from empirical studies about the actual learning processes that are associated with analogy assisted instruction since most of the studies have measured only the students' recall of learned materials. It is also not well known if analogies really do assist students to attain a level of conceptual understanding or whether students only use the analogy as another algorithmic method to obtain the correct answer.

The Constraints of Analogies

Despite the positive outcomes of analogies stated above, the use of analogies as a teaching tool can cause incorrect or impaired learning due to several fundamental constraints related to the analog - target relationship. Three of these constraints are analog unfamiliarity, the student's cognitive development and the incorrect transfer of attributes.

Analog Unfamiliarity: A significant constraint on the use of analogies in teaching is the learner's unfamiliarity with the analog selected by the textbook author or teacher. Several empirical studies on the use of analogical reasoning in chemistry instruction, for example studies by Gabel and Sherwood (1980, 1983, 1984), indicated that a significant proportion of students did not understand the analog sufficiently well. These results emphasise the need for caution in teaching with this method and in making instructional decisions based on an evaluation of those analogies that are presented to improve student understanding of chemistry concepts. A strategy that can be employed by textbook authors to reduce the problem of analog unfamiliarity is to provide additional 'analog explanation' concerning the analog and its relevant attributes. This will provide useful, additional information to the student. 'Strategy identification', where the author engages a term such as "analogy" or "analogous", may serve as a warning to students that careful thought is required to derive the full and correct meaning from the analogical statement.

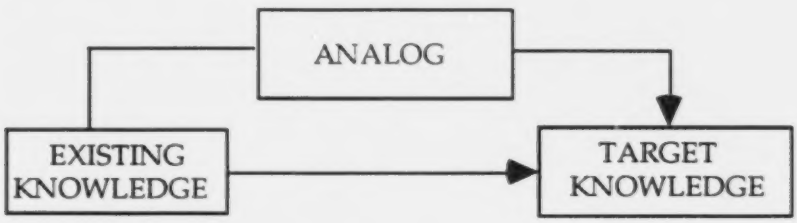
Student's Cognitive Development: A second area of constraint with analogy use relates to the Piagetian stages of cognitive development. There is general agreement that analogies can assist students who primarily function at lower cognitive stages; however, if these students lack visual imagery, analogical reasoning, or correlational reasoning, the use of analogies is still believed to be limited (Gabel & Sherwood, 1980). In addition, those students already functioning at a formal operational level may have already attained an adequate understanding of the target and the inclusion of an analogy might add unnecessary information loads that could also result in new misconceptions being formed by the students.

Incorrect Transfer of Attributes: The nature of the analog is that it has some shared attribute(s) with the target. However, it may be considered that the unshared attributes are as instructive to the students as are the shared attributes (Licata, 1988). No analog shares all its attributes with the target as, if it did, the analogy would then become simply an 'example'. These attributes that are not shared are often a cause of misunderstanding for the learners if they attempt to transfer them from the analog to the target.

Textbook authors may provide further mapping in an attempt to reduce the likelihood of the student incorrectly transferring analog attributes. Curtis and Reigeluth (1984) have reported that all of the 52 analogies found in four popular American chemistry textbooks

included some statement concerning the nature of the shared attributes although only 10 analogies had mapped more than one attribute to create an 'extended' analogy. This encouraging lack of 'simple' analogies was not, however, characteristic of science textbooks in general.

A related constraint occurs when the students attempt attribute transfer in an inappropriate manner. Rather than using the analog attributes as a guide for drawing conclusions concerning the target, the students occasionally incorporate parts, or all, of the analog structure into the target content. This is illustrated diagrammatically in Figure 1. One of the results of this incorrect transfer is that when students are questioned concerning the nature of the target content, they will answer with direct reference to the analog features. For these reasons, some instructors choose not to use analogies at all and thereby avoid these problems whilst forsaking the advantages of analogy use.



Desired use of analog to show the relationship between the existing and target knowledge structures. Analog attributes are used only to draw conclusions concerning the target.

Undesired effect due to the incorporation of the analog into the framework relating existing knowledge to target knowledge.

Figure 1. Incorporation of analog in new knowledge.

When analogies are used during classroom instruction, discussion should take place to assist in the delineation of boundaries and to aid concept refinement (Licata, 1988; Webb, 1985). Indeed, Glynn et al. (1989) have produced a six step Teaching-With-Analogies model that is designed to assist teachers use analogies effectively. This model provides for a clear delineation of shared and unshared attributes by the teacher. Allowing for student involvement and discussion at the classroom level also will provide feedback to the instructor if incorrect attribute transfer has occurred. Teachers should not assume that the students are capable of effecting correct analogical transfer unassisted but, rather, they should provide explicit instruction on how to use analogies and provide opportunity for classroom discussion on the subject. The highlighting of unshared attributes may also be done by a textbook author although documented evidence of this occurrence is rare (Curtis & Reigeluth, 1984). It may be that textbook authors assume that this is not required, or that teachers will conduct this aspect with the students in class

time. Recent research, however, indicates that teachers do not expand upon analogies contained in their students' textbooks when conducting their normal teaching routines (Treagust, Duit, Joslin & Lindauer, in press).

Research Focus

This study was conducted in two parts. Firstly, an examination of ten chemistry textbooks used in Australian senior high school chemistry classrooms was carried out in order to determine the extent and nature of the analogies. Specifically, the study investigated the frequency of analogies found in these textbooks; compared the frequency of analogy use for particular sections of the subject matter or at different stages of the curriculum; identified textbook authors' incorporation of instructional strategies that aim to directly assist the student to use analogies to aid understanding; and examined the type of analogies used most frequently in the textbooks.

Secondly, interviews were conducted with the authors of seven of the ten textbooks. Specifically, this part of the study solicited the views currently held by the textbook authors concerning analogy use; examined authors' reasons for inclusion or exclusion of analogies in instructional materials; any personal appeal for a model approach to analogy teaching; and investigated the changes the author would make to a later edition of their own textbook if they were provided with a more thorough repertoire of trialled, familiar analogies.

The two parts of this study are described separately followed by conclusions drawn from the results of both parts and implications for teachers, textbook authors, and educational researchers.

Analogies Used in Chemistry Textbooks

Procedure

Ten chemistry textbooks (see Appendix) were examined and all analogies identified were photocopied and further analysed. The textbooks used in the analysis had been identified by state syllabus organisations as those current, generally used textbooks for Australian senior secondary chemistry education. Only one of the textbooks, a British publication, was not published in Australia.

A portion of text or a picture was considered to be analogical if it was aligned with the working definition stated above (Glynn et al., 1989, p. 383) and/or it was identified by the author as being analogical. Each analogy was scrutinized concerning the following features, three of which (c,d, and e) were reported for American science textbooks by Curtis and Reigeluth (1984): (a) the content of the target concept; (b) the location of the analogy in the textbook; (c) whether it was verbal or pictorial; (d) evidence of further analog explanation or strategy identification; (e) the extent of the mapping done by the author; and (f) the presence of any stated limitation or warning.

Results

A total of 93 analogies were identified from the ten textbooks. This resulting mean of 9.3 analogies per textbook is less than the mean of 13 reported in the American study (Curtis

& Reigeluth, 1984). The number of analogies found in each book varied considerably with five books having less than six analogies whilst the other five had between 12 and 18 analogies. Each analogy was further classified independently by the two researchers with an original agreement of 93%. The remaining 7% of the classifications were agreed upon following consensus discussions.

Content Analysis: The content area of the target concepts were classified into 15 categories. Table 1 indicates that a considerable proportion of the analogies (21, 22.6%) relate to "Atomic Structure" - including electronic arrangement. Other areas in which analogies were used more frequently were found to be "Energy" - including collision theory - (11, 11.8%) and "Bonding" (12, 12.9%). The submicroscopic nature of these target concepts emphasizes the visualization role of analogies.

Table 1.
Analysis of the Frequency of Analogy Use Compared to Target Content Area.

Content Area	n	%
Acids & Bases	6	6.5
Analytical Methods	3	3.2
Atomic Structure	21	22.6
Biochemistry	6	6.5
Bonding	12	12.9
Chemical Equilibrium	5	5.4
Chemical Processes	1	1.1
Energy	11	11.8
Industrial Processes	1	1.1
Nature of Matter	8	8.6
Organic Chemistry	5	5.4
Periodic Table	2	2.2
Reaction Rates	3	3.2
Solutions	3	3.2
Stoichiometry	6	6.5

Analogy Location in Textbook: The page number of each analogy was used to determine a decile measure of the analogy's location within the textbook as a whole. Table 2 provides data which suggest that the analogies tend to be located more frequently in the earlier stages of the textbook except for a number found in the 7th decile. This could indicate that conceptual targets are encountered in two phases - initially when the new work is being introduced and also, at a later phase, when more difficult concepts are being presented.

Verbal and Pictorial Analogies: Forty four (47.3%) of the identified analogies had a pictorial component. These pictorial analogies included some diagrammatic representation of the analog. Further analysis revealed that pictorial analogies are frequently positioned in the margin, presumably as an anecdotal package of helpful information. However, as Table 3 illustrates, verbal analogies were rarely found in a marginalized position which indicates that authors may wish to use pictorial analogies more frequently but tend not to sacrifice the copy space. Those authors writing texts with

marginalized comments tend to make use of the opportunity to use this space for pictorial analogies.

Table 2.
Analysis of the Decile Position of the Analogies in the Textbooks as a Whole.

Location	n	%	Cum %
0	21	22.6	22.6
1	12	12.9	35.5
2	14	15.1	50.5
3	9	9.7	60.2
4	9	9.7	69.9
5	4	4.3	74.2
6	9	9.7	83.9
7	12	12.9	96.8
8	3	3.2	100.0
9	0	0.0	100.0

Table 3.
The Frequency of Use of Marginalized and Pictorial Analogies in the Textbooks.

	Marginalized	Text Body	Total
Verbal	5	44	49
Pictorial	25	19	44
Total	30	63	93

Further Analog Explanation or Strategy Identification: To avoid the problems of analog unfamiliarity and incorrect attribute transfer, some writers provided background information concerning the relevant attributes of the target domain. This analog explanation attempts to ensure that the student is focussing upon the appropriate attributes at the time of analogical transfer. The explanation may constitute a simple phrase of only a few words through to a paragraph thoroughly describing the analogy attributes: 56 (60.2%) of the analogies had some analog explanation which is a little lower than other reported research (Curtis & Reigeluth, 1984).

Further, only 15 (16.1%) of the analogies included any statement identifying the strategy such as "an analogy", "analog", or "analogous". It is likely that if 'strategy identification' was employed more frequently, then the effect would be similar to the addition of a warning in that it will direct students towards the correct cognitive procedure and the students may be less likely to transfer analog attributes incorrectly to the target (Glynn et al., 1989).

The Extent of Mapping: The extent of mapping used by the textbook authors was classified using Curtis and Reigeluth's criteria of 'Level of Enrichment': (a) simple - states only "target" is like "analog" with no further explanation; (b) enriched - indicates some statement of the shared attributes; and; (c) extended - involves several analogs or

several attributes of one analog used to describe the target.

The textbook analysis found that the use of simple analogies was fairly common (42, 45.2%) despite research suggesting that students require assistance when relating the correct analog attributes to the target. This figure is substantially greater than that reported by Curtis and Reigeluth for chemistry textbooks. Only 35 (37.6%) of the analogies were enriched whilst the remainder (16, 17.2%) were extended. Further, three of the six textbooks having 12 or more analogies contained considerably more simple than enriched analogies.

Limitations : Given that analogies can be used incorrectly by students and that research suggests that authors include some warning as to the limitations of the analogical process, each analogy was examined to see if it included either a general statement of the limitation of analogy use or a statement relating specifically to the unshared attributes in that analogy. No general statements concerning analogy use were made in any of the textbooks and only eight specific warnings or limitations were expressed. These data add support to the suggestion that authors are either assuming students are capable of effecting the analogical transfer themselves or that the teacher, in the course of normal classroom teaching, assists in this regard.

Discussion

While analogies were used slightly less than those in the U.S. study, specific areas of chemistry subject matter, characterized by their microscopic processes and abstract nature, used analogies most. In addition, the analogies tended to be more common in the early sections of the textbooks where prerequisite concepts are being established and authors may be more likely to engage student-friendly strategies. The link between visualization processes and analogy is borne out by the significant use of pictorial analogies. These were often positioned in the page margin beside the text which may indicate that one of the reasons why authors resist using more pictorial analogies, and verbal analogies also for that matter, is due to a lack of copy space.

Often, the authors employed further analog explanation and this must be encouraging to researchers although evidence of strategy identification was scarce. In addition, the number of simple (unmapped) analogies was found to be much higher than that reported in the U.S. study. This possibly indicates the authors' impression that the classroom teachers will provide further support to the analogy for the students. Similarly, little evidence was found of genuine attempts by authors to highlight the limitations of a stated analogy. This special form of mapping may also require the assistance of the classroom teacher if the analogy is to prove most effective.

Authors' Perspectives on Analogy Use in Chemistry Textbooks

Procedure

Semi-structured interviews were conducted with seven authors referred to as A, B, C, D, E, F, and G who represent eight of the ten textbooks analysed. Of the remaining two textbooks, one author was no longer in a position to be involved due to failing health and the other was overseas.

The interviews were conducted in a semi-structured manner as suggested by Yin (1989). Six of the seven interviews were conducted in person and lasted between 60 to 80 minutes. The other interview (with Author E) was conducted via a long distance telephone conversation which was tape recorded with that author's permission. During each interview, examples of analogies identified from the author's own textbook were used, wherever possible, to focus discussion and to assist in the definition of terms used by the interviewer and interviewees. All interviews were tape recorded and transcribed and subsequently the transcripts were analysed in an interpretive manner (Erickson, 1986) to address the research focus. At this stage, further reflective observations from the transcripts were provided by a colleague.

The results of the textbook analysis indicated that Authors A, E, and G used analogies more frequently (12, 14, and 14 analogies respectively) whilst the textbooks represented by the other four authors contained between one and five analogies. However, the textbook by Author E contained almost four times as many words as the other textbooks and, on an analogy by word count analysis, can be considered to contain a similar number of analogies to the textbooks by Authors B, C, D, and F.

Results

The characteristics of a good chemistry teacher: Each author was asked to briefly describe the characteristics of a good chemistry teacher to ascertain any general leaning towards pedagogical styles that would be particularly conducive or otherwise towards the use of analogies in textbooks.

Five of the authors (B, C, D, E, and F) strongly emphasized that the need for a strong background in chemistry was by far the most important factor. Comments, such as that of Author E, about the requirement of a teacher to be "totally on top of the discipline aspect", and by Author D, of the need for a content knowledge "way in advance of the level you are teaching" as being "the only way that you can have comfortableness, enthusiasm, imaginative ideas, different ways of presenting things" suggests that these authors consider that good teaching needs a foundation of good content knowledge. Having established this foundation, the authors stated that being interested in students and being able to suitably organise and select the content material were other characteristics of good teaching. For example, having commented upon the need for chemistry teachers to know their subject matter, Author F indicated that "secondly, you have to teach where the students start. You have to know where their knowledge is and what their interests are and start from that basis so that you can build on something." However, two authors (A and G) considered student-teacher relationships as the most important characteristics of good chemistry teaching. Author A stressed the need for the teacher to be interested in the thought processes of students, and to be "clear and precise, be fair, and be prepared to admit that you are wrong" whilst Author G proposed that "it's really mostly important just to get the students interested".

The meaning of analogy: The authors' ideas of what did, and what did not, constitute an analogy, indicated general agreement with each other and with the research literature. Some variances in the discussion, however, followed the lines of "all science is analogy" due to the use of symbols in instruction and descriptions of invisible processes and entities (Author C). One of the authors (D) discussed and demonstrated what could be described as a rice analogy for particle theory relating to the states of matter (Knox & George, 1990). It was agreed that this demonstration, although being analogical in nature, could better be described as an analog model. The authors demonstrated that they did not

confuse examples with analogies and they were able to clearly identify two discrete domains in the analogies that were discussed although, for several of the authors, there was evidence of a lack of delineation between "analogy" and "model".

Examples of analogies used in their own teaching: Each author was asked to recount several analogies used in their own teaching in order to provide insight into the authors' personal views of analogies in teaching so that a comparison could be made to the frequency of analogy inclusion in the textbook.

Four of the authors (A, B, C, and D) conveyed some difficulty recalling analogies that they had used in their teaching. Author E was able to instantly respond with an analogy that he had recently used in a teaching situation; however, this author had some prior warning of the questions due to the nature of the telephone interview arrangements. Author B suggested that he did not use analogies as frequently now as what he had done at the time when he was teaching chemistry using the Chem Study curricular materials and, in explanation, he commented that he was well aware of the research indicating that some of these analogies may result in the students forming misconceptions.

One of the authors (A) indicated several analogies that were in his textbook that he used in his teaching also. He suggested that the analogies lost something when they went to print because, when using them in the classroom, they could be presented in such a way as to foster interest and motivation more readily. He, like the others, indicated that analogy was something of a spontaneous exercise and that they were more likely to use analogies when attempting to explain an abstract idea to students after the students had indicated that they did not clearly understand. For example, Author C commented that "analogy is a very personal thing, something you might deal with on a one to one basis." Despite freely acknowledging that he used analogies in his own chemistry teaching, Author F also commented upon the need to change or adapt models and analogies to suit the changing circumstances of the lesson and pupils.

In a similar manner, all of the authors seemed to be aware that there was a need for analogies to be discussed by both teachers and students when they are used in a classroom setting. Having described his analogy for the semi-conductor, Author E commented that the analogy had been created spontaneously by him as a result of being questioned concerning the target concept by some students after a lecture. In this situation, he could "push it [the analogy] to outrageous lengths, then, when they've seen the point, you can, sort of, throw the analogy away and come back to the point you are trying to make." Author C suggested that when using analogies on the whole class scale, that he would build the analogy and then destroy it to illustrate where the analogy broke down. He proposed that the instructional value was in the resulting discussion and evaluation of the unshared attributes rather than in the construction or presentation of the analogy. Author B, when questioned concerning a particularly problematic analogy for chemical equilibrium commented that "maybe the way to deal with it is to point out what's wrong with the model." Later, with respect to the same analogy, he suggested that "I wouldn't mind using it myself if I had control of the situation in a classroom situation" but he went on to indicate the lack of control available once the analogy is in textbook form by adding "but I wouldn't like to stick it in a text where everybody is going to use it."

This theme of the inability to negotiate analogy once it is in text was taken up by several authors. For example, Author A commented that "many analogies work much better in the teaching situation than they do as presented in books." Author B felt likewise and suggested that he preferred to use them himself "rather than put them in written form .... I don't really want to lock an analogy into concrete." Author E, commenting from a

similar viewpoint, proposed that "there is a bit of a danger that students can get the analogy confused with the reality". Similarly, Author C responded that "I would be reluctant to use an analogy in a textbook because I don't know that you could ever, in words, provide an adequate representation for all students." Later, he emphasized that when you are teaching you can respond to those students who do not understand the concept by an analogy or further explanation but that "you don't see the blank faces of the students you are writing the text for."

One important feature that arose was the degree to which the authors anticipated that the classroom teachers would engage themselves in explaining the content of the textbooks to their students. For example, when asked about the need to identify analogies found in the textbook with some strategy identification, Author F remarked that he didn't know if they'd described it as an analogy in the textbook but that "certainly I would teach it that way... I don't think we put teaching techniques in the textbook." This author went on to describe an example of how he taught using analogies directly from the textbook, highlighting things that the two domains had in common as well as any limitations. Author G also was able to describe how she taught directly from the textbook and discussed the analogies with the students in the classroom. However, that author remarked that, whilst "it was the teachers' role to explain [what was in the textbook], ... if the student was away, the textbook should be sufficient instruction". Further, Author B indicated that the book was clear enough that students should be able to work through it themselves without undue difficulty. This could indicate that textbook authors do not presuppose that teachers, in normal circumstances, will explain analogies and analogy limitations to the students in many cases.

Students' understanding of analogies: Often, comments were made by the authors concerning the interactions that the students might have with the analogy and the process of analogy. When asked why he decided to include a particular analogy in his text, Author D responded in terms of traditionally accepted advantages for analogy inclusion by stating that "we use an analogy that is in our experience, that is ... something we can relate to and can visualize ." Author C remarked that we use analogy "to help put something into a language that the students can understand ... to make the complex commonplace" whilst Authors F and G referred to analogies "relating to real life activities" and being "something familiar" respectively.

These authors have identified the 'visualization' advantage and the 'student world' advantage, yet not the 'motivational' advantage of analogy. It is also interesting that Author D considered that the analogy should be in "our" experience and as being something that "we" can relate to. This is important when compared to the comments of Author C who, reflecting back on some research he conducted in classrooms, recalled a student making a statement to the effect that:

> Analogies are very personal things. What's a good analogy for Mr X is not a good analogy for me because I don't think the same way that Mr X does. It's alright for Mr X - he knows the whole story. I don't! You're trying to present an analogy to me when you know what all of it means. You know what is coming up and you are aware of the history behind that. Here I am, as a student in the first couple of weeks of my senior chemistry course, being thrown into this same thing. I don't know what the end of the story is like. It's like trying to use information that I am going to get in chapters 7, 8, and 9 of my novel to answer a dilemma that I have in chapter 1.

Author C also acknowledged that, whilst the students' ability to deal with the analogy

should not be overlooked, the need for analogies varied markedly from student to student. He believed that the need is related more to academic ability and suggested that "there have got to be some students who will need a little bit more information and there will be other students who will say 'this is pretty tedious stuff'." In a related discussion, Author D argued that

> You put it off to the side because it's something you could elude to and is maybe useful but it doesn't interfere with the flow and it's not necessary for the flow and not everyone would need it but it's there if you want to go that way.

Awareness of, and appeal for, a model approach to analogy teaching: With this question, the researchers wished to ascertain which, if any, of the authors recognized Glynn et al.'s Teaching-With-Analogies model or were aware of this or any other models relating to analogy presentation. In addition, the authors were asked to comment upon their perception of the usefulness of such a model for textbook presentation of analogies after having studied it for several minutes.

None of the authors recalled ever having seen or used a model for analogy presentation. One of the authors (C) was aware of the work done by Clement on bridging analogies in physics (Clement, 1987) and Author B commented upon the similarity of the model to an established approach for the teaching of concepts (with attribute analysis, examples, and non-examples). Author E was content with the model as it was presented and indicated that it was common sense and that "most experienced teachers would do that without even being conscious that they were doing these things." The other authors did appear to accept the six step model as useful although some suggested variations and alterations, while others (A, D, F, and G) acknowledged that they considered that the best approach varied depending upon the analogy and the setting. The problem of extra length to a textbook was raised by Author F who proposed that analogies in this model approach could be better placed in a teachers' guide to the textbook. Author G cautioned that, whilst there was nothing wrong with the model, he would "never like to see a recipe for how you teach."

Other useful comments came from Author B who suggested that the limitations of an analogy could be presented at the same time as the similarities - that is, before the conclusions are drawn. Author D attempted to clarify the conflict that arises over the use of an analogy to draw conclusions rather than to confirm a previously arrived at conclusion by remarking that:

> There certainly must be cases where the conclusion has already been made and, in an attempt to make sense of that conclusion, you might use the analogy. Though, I suppose what you are at least doing is drawing out the conclusions of what you have previously done before.

The authors' comments indicate a general acceptance of the model approach for analogy presentation provided that due regard be given for flexibility in various settings.

Proposed future use of a bank of trialled analogies: When asked if they would be interested in incorporating some of a bank of trialled analogies in a fictitious new edition of their texts, several of the authors indicated some reluctance. Author C clearly stated that he "wouldn't use them in the textbook" whilst Author B only agreed to the inclusion on the proviso that the "person writing the book felt comfortable." Similarly, Author E indicated that he would consider them but he would "need a fair bit of

convincing that an analogy was a valid one." Authors of the more recent texts (Authors F and G) indicated little willingness to deviate from their current texts. On further questioning, however, four authors showed particular interest in having these trialled analogies available in the form of a teachers' guide. Author E showed enthusiasm for the idea whilst Author D proposed that each analogy "could have a blurb on each of the six steps". In addition, Author C suggested that he "might be interested in putting them in a teachers' guide." He qualified his concession, however, by proposing that, even in a teachers' guide, there would be the need for some form of instruction to teachers that "clearly you don't just take these into the classroom cold and assume that all your students, at the end, will be enlightened." Alternatively, Author F suggested that although you could embed these analogies into another chemistry book, there would be demand for a "book of analogies.... that's related to a number of chemical concepts that are pretty universal".

Discussion

This part of the study has highlighted differences in the authors' approach to analogy that may explain the variations in the frequency of analogy inclusion in the textbooks examined in the first part of this study. Generally the authors felt uncomfortable about setting analogies into print as the sense of control and flexibility by the teacher is lost. Most consider that analogies should be used by teachers as a negotiated response strategy to be used when the teacher considers that an explanation to the student/s about particular concepts have been unsuccessful.

The author's reasons for including analogies in their textbooks coincided with two of the main advantages of analogies as reported in the literature - namely, the provision of a 'student world' view and the improvement of the visualization process; however, they did not directly recognise the reported advantage of improving student motivation. Those authors who have used analogies infrequently in their textbooks tended to place more importance upon the teachers' subject matter knowledge than upon their maintaining students' interest and developing relationships. A further factor that may have limited the use of analogies was the space that they require in the textbook. Most of the authors made incidental remarks, during the interviews, of the pressure that they were under by publishers to keep the textbook to the smallest possible size and price.

The authors were not familiar with any models that guided analogy presentation in textbooks or in teaching. However, upon perusal of such a model, most of the authors suggested that it could be useful although they expressed a desire to have some flexibility in the order of the stages of the model depending upon the teaching situation. The interviews with the authors showed that the use of analogy in the page margins of some textbooks reflects the perception of the author that the analogy is something that many students can do without and should, therefore, simply be made available to those students requiring a further explanation of the concept under study.

Those authors who had used analogies sparingly in their textbooks showed little or no inclination to include them in a later, fictitious textbook. One author, who used analogies frequently in both the textbook and in teaching, suggested that there would be no change in the future edition. The authors expressed interest in the inclusion of a bank of trialled analogies into a teachers' guides where an approach such as the Teaching-with-Analogies model could be used to assist teachers in their teaching with analogies. Support for a resource book of chemistry analogies was also voiced.

Conclusions

Research into how students and teachers use analogies in the learning/teaching enterprise indicates that enriched analogies, rather than simple analogies for all but the most elementary relationships, increase the effectiveness of analogical transfer and hence, the understanding of the target domain. Similarly, research suggests that analogies used in textbooks where there is a lack of instruction or assistance in using the analogical processes, and a scarcity of stated limitations, are less useful than when these features are included. In analysis of the ten textbooks reported in this study and the interviews with the authors, both these issues would appear to require greater attention in order to optimise learning of concepts by analogy use. The authors of the textbooks have assumed that the classroom teacher will use the analogies in such a manner to enhance their pedagogical use. However, there is no research evidence to support this suggestion since teachers' pedagogical content knowledge has been known not to be generally extensive in this regard (Shulman, 1986; Treagust, et al., in press) and the interviews with the authors provided no recommendations of what teachers were expected to do with the analogies and, with the exception of two textbooks, teachers' guides were not written for the textbooks.

Glynn et al. (1989) described analogies as double-edged swords and the chemistry textbook authors would in many instances identify with this perception. However, the inclusion of analogies in the textbooks written by these authors reflects variations in the authors' perceptions of the advantages and disadvantages of analogy use as well as reflecting variations in their respective teaching backgrounds. The frequency of analogy inclusion in the textbooks does not seem to be indicative of the willingness of the authors to use analogy in their own teaching; rather they are unwilling to set the analogy to print because of their belief that teaching with analogies should involve discussion or negotiation with the students. This is not possible in a textbook situation.

The unfamiliarity of the authors with research guides regarding analogy presentation highlights the problems of the efficient dissemination of research findings in science education to practitioners. However, the willingness of the authors to accept a model approach to analogy, albeit a more flexible one, indicates the usefulness of such an approach. Also, it should be considered that there is still a lack of empirical research findings suggesting that analogy presented in the model format aids student understanding more than other analogies.

As we observe chemistry teachers and their students in regular classroom settings using analogies to better understand complex concepts, we anticipate that we will be able to determine for whom and under what conditions analogies are most beneficial in secondary school chemistry. Subsequently, we plan to provide materials, in the form of a teachers' guide, which is consistent with the recommendations of the textbook authors and which will enable analogies to be used by chemistry teachers and their students in an exemplary fashion.

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APPENDIX: TEXTBOOKS ANALYSED

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